Things of science

sponsored and distributed without profit by Science Service, Inc., The Institution for the Popularization of Science, 1719 N Street, N.W., Washington, D. C. 20036. E. G. Sherburne Jr., Director. Ruby Yoshioka, Editor.

SUNDIAL

Unit No. 332

Copyright© 1968 by Science Service, Inc.

SUNDIAL

This unit of THINGS of science contains a lead sinker, nails, string, wire, plastic tie wire, protractor, ruler and colored papers, materials for use in the study of the principles and construction of sundials.

Today we usually look upon sundials as decorative pieces for gardens, interesting museum objects or unusual artistic creations, but seldom, if ever, seriously as timekeepers. However, for thousands of years man depended primarily upon the sundial to tell the time of day, and it is only since the beginning of this century that it has been completely replaced by mechanical timepieces.

Although the sundial is not generally regarded as a reliable timekeeper, when made with precision it can be very accurate, and in the early years of watchmaking, the still crude clocks and watches were checked and set by the sundial.

The sundial is an instrument that uses the moving shadow cast by the sun to tell time. It tells solar time. The sundial therefore is useful only during the daylight hours and only on sunny days. On days when it rains or the sky is clouded it is useless.

However, in spite of this handicap

and a number of other disadvantages, the sundial was a very useful instrument. At the peak of its popularity the sundial was made in all shapes and sizes, some very simple and others elaborate works of art and science.

How does one tell time by these instruments and what are the principles underlying their structure?

You will find the answers to these questions when you make the sundial models described in the following pages.

First identify your specimens.

LEAD SINKER—To be used for making a plumb line.

STRING—For plumb line.

NAILS—Two; one with head and one without.

WIRE—Fine cotton-covered wire for construction of heliochronometer.

PLASTIC TIE WIRE—One-fourth-inch wide double-wire plastic tie.

PROTRACTOR—Cut out carefully.

RULER—Inch and centimeter; cut out carefully.

COLORED PAPERS—For construction of sundials; 1 salmon; 2 green; 2 pink; 1 blue.

TABLE—Values for equation of time.

Note: Experiments 2 and 3 require a period of time. Therefore, you might

want to carry on the other experiments at the same time.

EARLY SUNDIALS

Time was important to primitive man just as it is to us today, for he could hunt for food or do necessary chores only during the daylight hours.

He must have discovered very early in his history that the passing of time could be observed by the movement of shadows cast by the sun as it appeared to travel across the skies. The first sundial could have been a tree or other shadow-casting object. A straight branch cut from a tree could have served as a portable sundial for him when out hunting or fishing.

Experiment 1. Let us see how well we can tell tell time by a simple shadow.

First make a plumb line with the lead sinker and string in your unit. If the hole in the sinker is too small for the string enlarge it slightly by inserting a paper clip or similar wire. Pass the string through the hole from the narrow end of the sinker and knot the end of the string.

Next push the headed nail through the center of a large piece of cardboard so that it stands perpendicular with the pointed end up. Secure the nailhead to the cardboard with tape. Be sure the nail is vertical and the cardboard perfectly hori-

zontal. Check with the plumb line.

You now have the most primitive form of sundial (Fig. 1). The nail is the gnomon and the horizontal cardboard the dial plate on which the hour lines will be drawn. A gnomon is any object that serves as an indicator by its shadow.

The gnomon and dial plate are the two basic and essential parts of any sundial.

Place the sundial in a spot where the sun will strike it all day from sunrise to sunset. At exactly one-hour intervals mark the top of the shadow cast by the gnomon on the dial plate with pen or pencil and write down the time next to it. Observe also when the shadow is shortest and mark the top of the shadow noting the time. You will have to watch for this starting a few minutes before 12 o'clock standard time.

At the end of the day draw lines from

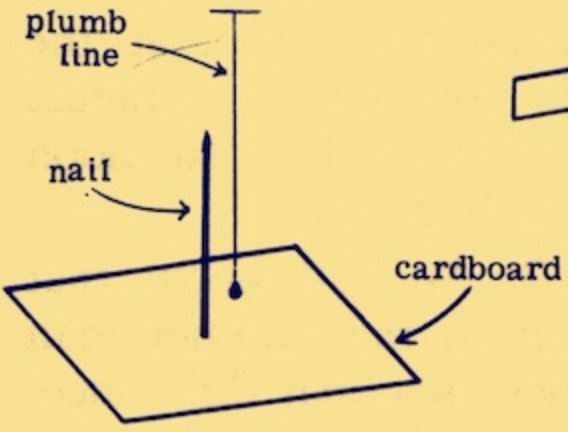

Fig. 1

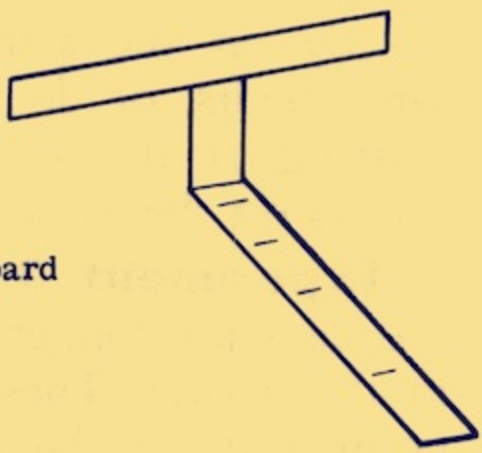

Fig. 2

the points to the base of the gnomon. These are the hour lines.

Note that the shadows shorten as the sun rises in the sky. The shadow is shortest when the sun is at its zenith, or at the highest point in its path. At this point the sun also crosses the meridian of your location.

The meridian is an imaginary line directly overhead encircling the earth and passing through the North and South Poles and through the zenith of that location. When the sun crosses the meridian it is noon solar time.

Note that solar noon is not necessarily 12 o'clock standard time. The explanation for this will be found in later experiments.

Experiment 2. Leave the sundial in exactly the same position for several successive weeks and mark the hours every five days or so. Do the shadows fall exactly on the same hour lines at the same hours, or do you notice a gradual shifting of the shadows? Is solar noon always on the same hour line?

Experiment 3. We all know that the days are longer in the summer than in the winter. These seasonal differences occur because the earth is tilted at an angle from the sun.

With the sundial in exactly the same position, make and keep shadow pictures for the first day of each of the four seasons, or for the closest convenient day, during the year, marking points at each hour as in Experiment 2. Compare the lengths of the hours of the different seasons by measuring the angles between the hour lines with your protractor. When are the hours the longest? The shortest?

Any upright object outdoors can be used to make such a sundial. The huge obelisks known as Cleopatra's Needles are believed to have been used as sundials in ancient Egypt. However, you can see from your experiments that since the position of the shadows change from day to day, this type of sundial is not the most satisfactory timekeeper, and its usefulness is limited probably to indicating solar noon.

A simple instrument shaped like a T with an elongated base is the oldest sundial uncovered by archaeologists and is believed to have been used in Egypt about 1500 B.C.

This sundial was placed so that the sun cast a shadow on its long narrow base (Fig. 2). To tell time with this instrument, the crossbar had to face east in the morning and west in the evening.

Experiment 4. You can make this simple dial with cardboard. The crossbar should be long enough to cast a shadow on the base. To keep the crossbar upright, cut a strip from your ¼-inch wide plastic tie wire about 5 inches long (not more since you will need the rest for a later experiment) and bend it into a right angle. Tape it to the right angle of the sundial. The rigid tie will hold the bar upright. The gnomon must be vertical so check it with your plumb line. How accurate would such a sundial be?

These two dials are examples of the earliest types of sundial and were very unsatisfactory for most purposes.

The development of the sundial into an accurate timekeeper took many hundreds of years paced by man's intellectual progress and his gradual understanding of the solar system, advancement in mathematics and the need for keeping accurate time as the world became more complex.

Early in the Christian Era it was discovered that if the gnomon was slanted so that it pointed to the north celestial pole, the shadow cast by the sun would show true solar time each day throughout the year.

Some 800 years later, the precise con-

struction of sundials was made possible by the development of trigonometry. Man could now calculate the exact direction of the shadow that would be cast by a particular gnomon at a given location.

With the convenient division of the complete day into 24 equal hours about the 15th century and the acceptance of the theory that the earth traveled around the sun and not the sun around the earth, the sundial came into its own.

From the 15th century until the 20th sundials were made in every imaginable form and size.

MEASURING TIME BY SUNDIAL

How does a sundial tell time?

As the earth rotates on its axis from west to east, the sun seems to move in a path from east to west. This is referred to as the apparent motion of the sun because as we all know, the sun does not actually travel across the sky but only seems to. As the sun moves from east to west it casts moving shadows from west to east.

Once each day, or every 24 hours, the earth makes a complete rotation on its axis. If you took your nail and cardboard sundial and placed it upright on the North Pole, its shadow would make a complete circle of 360° around the gno-

mon and the hours marked off equally would form 24 arcs of 15° each and each degree would equal four minutes. If these lines were extended to the South Pole, the earth would be divided into 15° sections of one hour each.

Since solar time is different in each locality due to the movement of the earth, as a convenience a standard for calculating time was established by international agreement. The earth was divided into 24 time zones of 15° each with Greenwich, England, designated as the prime meridian with a longitude of 0°. Standard time throughout the world therefore is now determined by the time at Greenwich. Half of the world is east of Greenwich and the other half west of Greenwich, each consisting of 180° and meeting directly opposite Greenwich at the International Date Line.

Each half is divided into 12 time zones of one hour each and spanning 15°. Since city and state limits do not always coincide with the 15° lines the boundaries for the time zones are shifted in most areas. In the continental United States, there are four time zones having the following time meridians: Eastern, 75° west; Central, 90° west; Mountain, 105° west; and Pacific, 120° west. As the time difference

is one hour for each 15°, it is easy to calculate the time for any of the other zones at any particular time of day from your location. If the time zone is west of you, subtract one hour for each zone. If it is east of you add one hour for each zone.

Thus, if it is 10 a.m. in California (Pacific Standard Time) then it is 1 p.m. in New York (Eastern Standard Time).

Experiment 5. What time is it in Chicago, Ill., when it is 5:00 p.m. in Buffalo, N.Y.? Find the longitudes on a map.

In order to standardize time within each 15° zone, the time for each time meridian is the time for the entire zone. Therefore, if standard time is desired from a sundial, which gives local time, we must take this fact into consideration.

EQUATION OF TIME

If we compare the apparent solar time as shown on the sundial with the time given on a clock we find that sundial time is sometimes behind and sometimes ahead of standard time.

This is because the construction of the watch is based on the assumption that all days are exactly equal in length and made up of 24 exactly equal hours. But this is not actually so. The length of each day varies slightly from one day to the next due to the elliptical path of the

earth around the sun and other rather complicated factors.

For the sake of convenience, however, it is essential that the clock show equal divisions of time, so an average length of day was calculated and the clock tells us time by average or mean solar time.

Therefore, when reading apparent solar time on the sundial or local solar time, the time will differ from the mean solar time of the clock and a correction must be made on sundial time to obtain clock time.

This is done by adding to or subtracting from sundial time a value known as the equation of time, which is the difference between the mean solar time and the apparent solar time (see Equation of Time table enclosed in this unit).

This correction will give you the mean local time. The clock, however, tells standard time. So a further conversion is necessary.

To do this you must know the standard time meridian of your time zone and your exact local longitude. Find the difference between the two in degrees and multiply the difference by 4 to find the number of minutes. If your longitude is located west of the standard time meridian add the difference to the mean local

time, if east of it subtract the amount. This will give you the standard time.

The correction for sundial time to standard time at any location can be made by this general formula: Standard time = local time ± equation of time ± 4 × difference in degrees longitude.

To convert degrees to time remember that there are 360° in a circle and each degree contains 60 minutes of arc and each minute of arc 60 seconds of arc. Also, each hour contains 60 minutes of time and each minute of time 60 seconds of time. In converting arc to time, if the difference in degrees is 2° 5′ 30″, the time difference would be 8 minutes, 22 seconds ($1° = 4^m$; $1′ = 4^s$; $1″ = 1/15^s$).

To calculate the standard time from a sundial reading of 12:00 noon on April 1 at longitude 76°W, for example, you would look up the equation of time for that date = 4. The mean local time then = 12:04 p.m. To convert this to standard time for 76°W, find the difference between the longitude and the standard meridian which is 75°W (eastern time zone) = 4 minutes. Add this to the mean local time since the location is west of the standard meridian. Standard time = 12:08 p.m.

Experiment 6. If sundial time is 1:15

p.m. on January 6 at longitude 91°, what is the standard time?

CONSTRUCTING A SUNDIAL

First of all, when constructing a sundial, you must determine the true north-south position or meridian and the exact latitude of the location for which the sundial is being made.

Experiment 7. Calculate the exact time that the sun will cross the meridian on the date of your experiment by adding or subtracting the equation of time from 12:00. Then correct to standard time. Check your watch to be sure it is exact.

Draw a straight line across a sheet of stiff paper or cardboard and place on a sound horizontal support outdoors. Suspend your plumb line above the paper from a stable support protected from the wind. Do not allow the plumb line to touch the paper (Fig. 3).

A few minutes before the sun is ex-

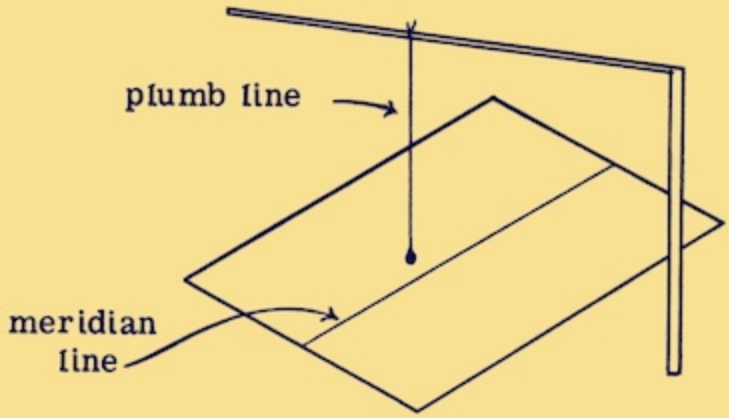

Fig. 3

pected to cross the meridian, allow the shadow of the plumb line to fall along the line you have drawn on the paper. As the shadow moves, move the paper along with it keeping the shadow on the line until the exact moment when the sun is on the meridian. Then secure the paper to the support being careful not to shift the position of the line. Keep this line intact as your permanent guide to align your sundial models.

HORIZONTAL DIAL

The horizontal dial invented by an Arabian was the most common form of dial. It gives true solar time throughout the year if properly constructed, but is useful only in the latitude for which it is made.

Experiment 8. Obtain a sheet of unlined paper at least 8½ inches by 11 inches in size to diagram the dial plate. Find the latitude of your location from a map or a local surveyor.

At the center of this paper, draw a rectangle, 3 x 3½ inches, across the width of the paper (Fig. 4a).

Draw a line EF lengthwise through the center of the rectangle to represent the 12 o'clock line.

Draw the line GH ½-inch from the edge for the 6 o'clock line.

Draw a line XY parallel to and two inches below GH. Extend this line to the edges of the paper.

Mark the intersections of GH and XY with EF, O and Q.

To locate the hour lines, you must find the length QP.

QP = OQ x sine of the latitude angle.

To find QP draw a right angle triangle having a hypotenuse equal to OQ (2 inches) and a base angle equal to the latitude of your locality (Fig. 4b). The altitude of this triangle Q′P′ is equal to QP. Measure Q′P′ with your ruler and draw in line QP.

Place the center of the protractor on P on a line parallel to CD and mark off 15° intervals from 0° to 180°

Draw radii through these points from point P and extend them to line XY.

Connect each of these intersecting points on line XY with 0. These lines are the hour lines. You will have 5 lines for the hours between 6 and 12 on each side. Extend the hour lines to the edges of the rectangle. Number the hour lines as shown.

Now cut a piece 3½ inches long from the pink card. Draw a line lengthwise down its center. This will be the 12 o'clock line. Draw in the 6 o'clock line

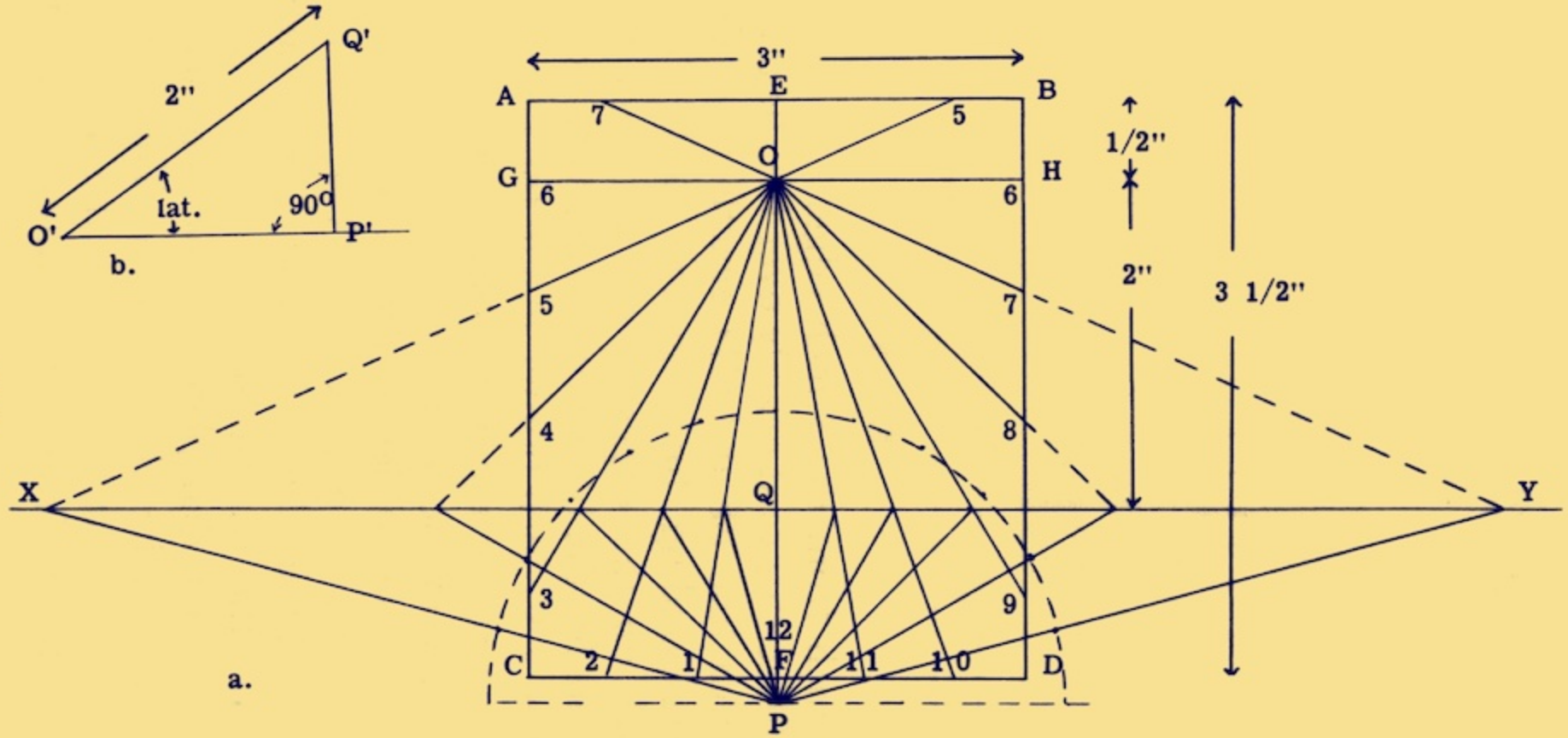

Fig. 4

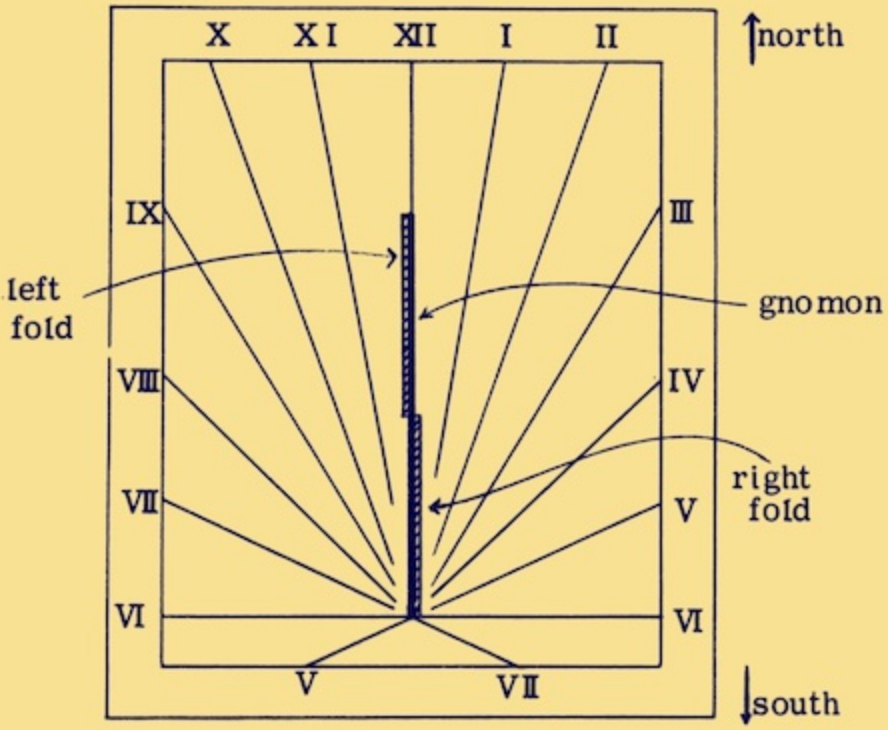

Fig. 5

½ inch from the 3-inch edge.

Place this card exactly over the diagram so that line EF and GH exactly meet the corresponding lines on the card. Then mark on the edges of the card, all the points for the hour lines, being very exact. Draw a ¼-inch border inside the edge of your card for the hour designations.

Draw in the hour lines from the inner line of the border to the intersection of the 6 and 12 o'clock lines (Fig. 5).

To obtain the 5 a.m. and 7 p.m. lines extend the corresponding p.m. and a.m. lines. Your dial plate is now completed.

Next make the gnomon. The angle of the indicating edge of the gnomon with the horizontal base must be equal

to the latitude of the location. The gnomon will then point to the north celestial pole when the dial is placed due south.

Construct the gnomon from the second piece of pink paper (Fig. 6). Draw line AC′ about ¼-inch from the narrow edge of the card. Using this line as the base-line measure off the degrees of latitude then draw line AC. This is the indicating edge of the gnomon and when in position will be parallel to the earth's axis.

Measure two inches from A to B. Draw line BC as shown. Cut out the gnomon including the extended baseline FD. Cut along dotted line GE. Fold along line BG to the left and GA to the right.

Paste the gnomon exactly on the 12 o'clock line with point A at the intersection of the 6 and 12 o'clock lines. The dial plate must be exactly horizontal and the gnomon vertical. Check the gnomon

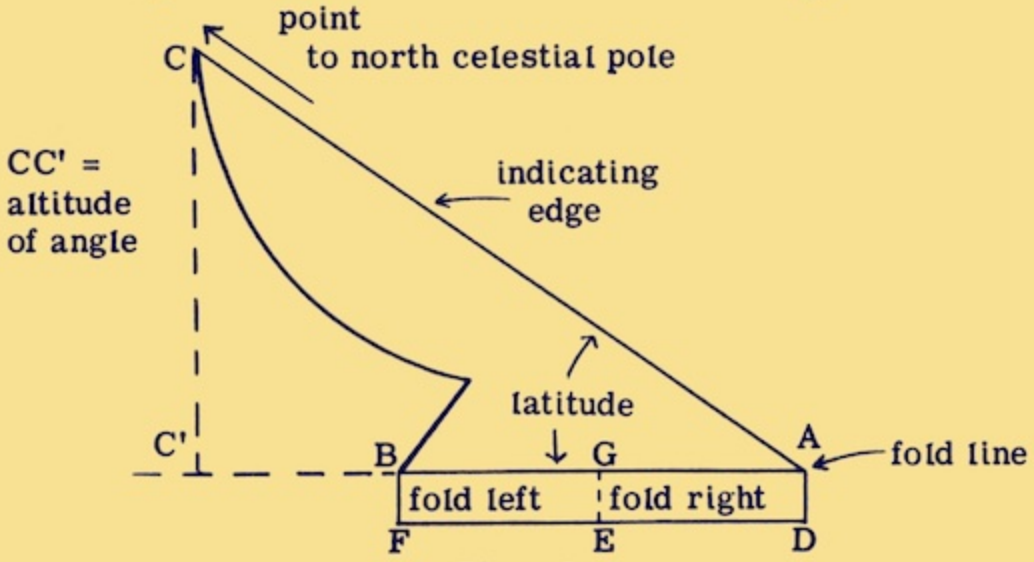

Fig. 6

with your plumb line. Be sure the angle of the gnomon to the base is 90°. Place the 12 o'clock line in exact north-south position using your meridian guide pointing the gnomon to the north celestial pole. The sundial is now ready to tell time.

VERTICAL SUNDIAL

Interesting curiosities, vertical sundials are still found on old buildings and churches in Europe and elsewhere. They were not as widely used as the horizontal sundial, perhaps because their time telling ability was more limited. When you make your model you will understand why this is so.

Experiment 9. The sundial made to face due south is the most accurate of this type.

Using the blue card, construct the dial face in the same way as you did for the

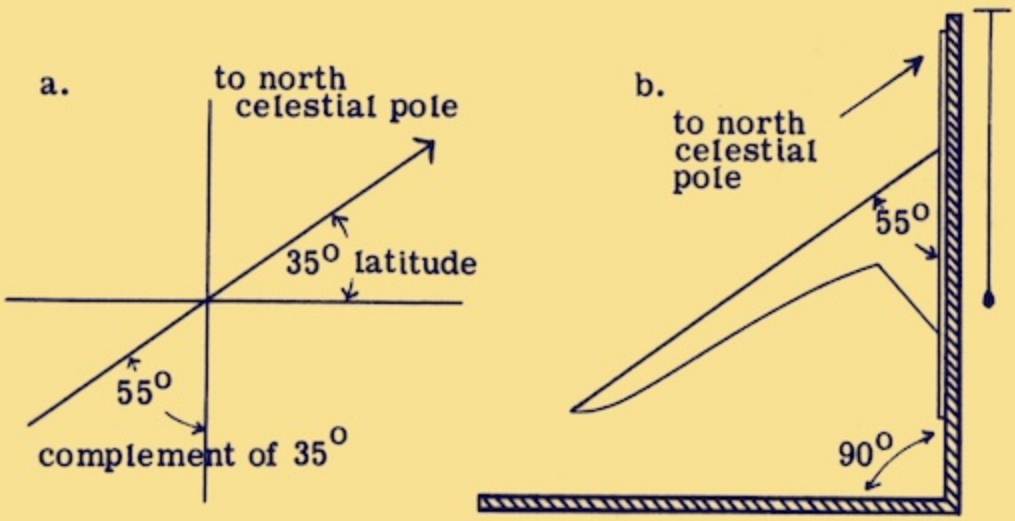

Fig. 7

horizontal dial, except here the angle of the gnomon is made equal to the complement of the latitude (Fig. 7a). The gnomon will then lie parallel to the earth's axis. Also place the a.m. hours to the left and p.m. hours to the right.

Construct the gnomon from the remaining pink paper and mount on the dial as on the horizontal dial.

Make a vertical support for your sundial with cardboard bent at a right angle, or from the bottom and one side of a stiff cardboard box. Draw a continuous line down the center of this right angle structure. Glue the sundial to the vertical side with the tip of the gnomon facing downward and the 12 o'clock line directly on the line on the support (Fig. 7b).

Align the central line on the base of this structure with your meridian guide line to obtain the true north-south position, facing the sundial due south. Use your plumb line to be sure the dial is vertical.

The shadow of the gnomon will fall directly on the 12 o'clock line every day of the year at solar noon if the sundial is accurately constructed.

Experiment 10. Compare the efficiency of the horizontal and vertical dials.

Experiment 11. Vertical dials may be made to face east, west and north also. Construct such dials by experimenting as people did in the early days before the time of protractors and mathematics. How accurate can you make these dials?

EQUATORIAL DIAL

The equatorial dial is so called because the plane of its dial is on the plane of the equator. Its gnomon which points to the north celestial pole is in line with the earth's axis and therefore perpendicular to the dial plate. This sundial is one of the most convenient types since it can be used anywhere on the earth by tilting to correspond with the latitude of the area.

Experiment 12. On a green card draw a circle about 3 inches in diameter. With your protractor mark off intervals of 15° all around the edge of the circle.

Draw lines from the 15° points to the center of the circle. These are the hour lines (Fig. 8a). Designate the 12 o'clock and six o'clock lines as shown. Mark the the intervening hours, a.m. hours at the right and p.m. hours at the left.

Do the same on the other side of the card but with the hours reversed. In order to show the time throughout the year, the hours must be shown on both faces of the dial. Otherwise, only the time dur-

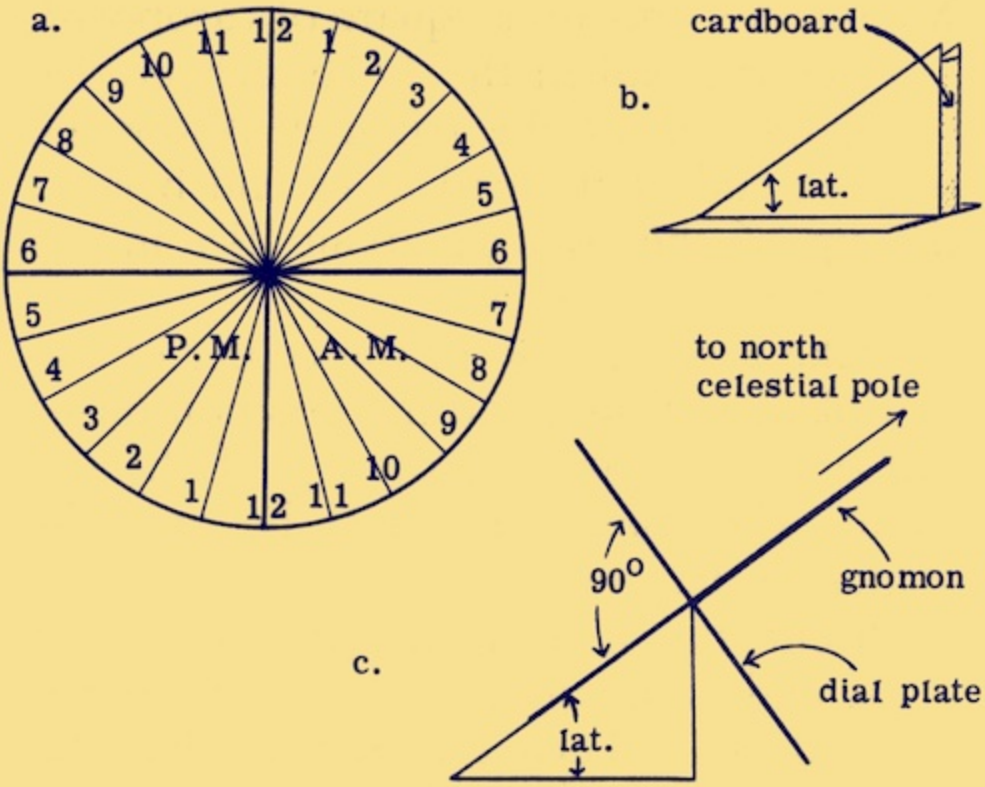

Fig. 8

ing the summer months between the equinoxes will be shown. Why?

The headless nail will serve as the gnomon for this dial. Check to see that it is perfectly straight.

Cut out two right triangles with the base angle equal to the latitude, extending the base ¼-inch as before for mounting purposes. Make a triangle of similar shape from heavy cardboard but do not extend the base. Cut the triangle about 1/16 of an inch deeper along the hypotenuse (Fig. 8b) Fold the colored pieces at the base line. Then paste the three triangles together with the cardboard piece in the center and baselines matched.

Mount this unit on a square of cardboard.

Place the nail in the 1/16-inch groove along the top of the triangle. Allow the pointed end of the nail to extend beyond the tip of the triangle about 2½ inches and secure with tape.

Make a small hole in the center of the dial plate and insert on the gnomon pushing it down gently to the tip of the triangle. The dial plate must be at right angles to the gnomon (Fig. 8c).

Orient the dial using your meridian guide and point the gnomon to the north celestial pole. Turn the dial so that the center of the shadow of the gnomon will fall on the 12 o'clock line at 12 noon standard time. The time is read by the center of the shadow. The dial will then give you standard time without corrections throughout that day, but not on other days because of the equation of time. How would you find standard time on succeeding days?

If you should go to another latitude, just change the angle of the mount.

To read the time in winter months, push the dial up on the nail and secure it so it will stay in position and read the time on the back of the dial.

HELIOCHRONOMETER

Of the various types of sundials the

heliochronometer is the most accurate. When precisely built it can tell time accurately to within a few seconds. This instrument like the equatorial dial may be used to tell standard time except for the equation of time.

Experiment 13. Cut two strips from your pink paper, 5/8 x 5 inches in size. On one of the strips draw a line across the width at its exact center. Then from this point mark off lines one centimeter apart in each direction for six centimeters. These will be the hour lines for your heliochronometer. Make the center line the 12 o'clock line (Fig. 9a), then number the other hours including lines to represent half hours if you wish.

Cut a five-inch length from your plastic tie wire and secure this to the back of the strip, taping it down at each end. Now mold the strip gently so that it forms an exact semicircle with the six o'clock lines as the limits of the half circle.

Draw a line down the length of the second strip at the exact center. Secure a 5-inch piece of plastic tie to the back of this strip also, and at the center of each end cut a tiny notch (Fig. 9b). Mold this into a half circle. This is the meridian arc. Insert the meridian arc between the time dial and its plastic support

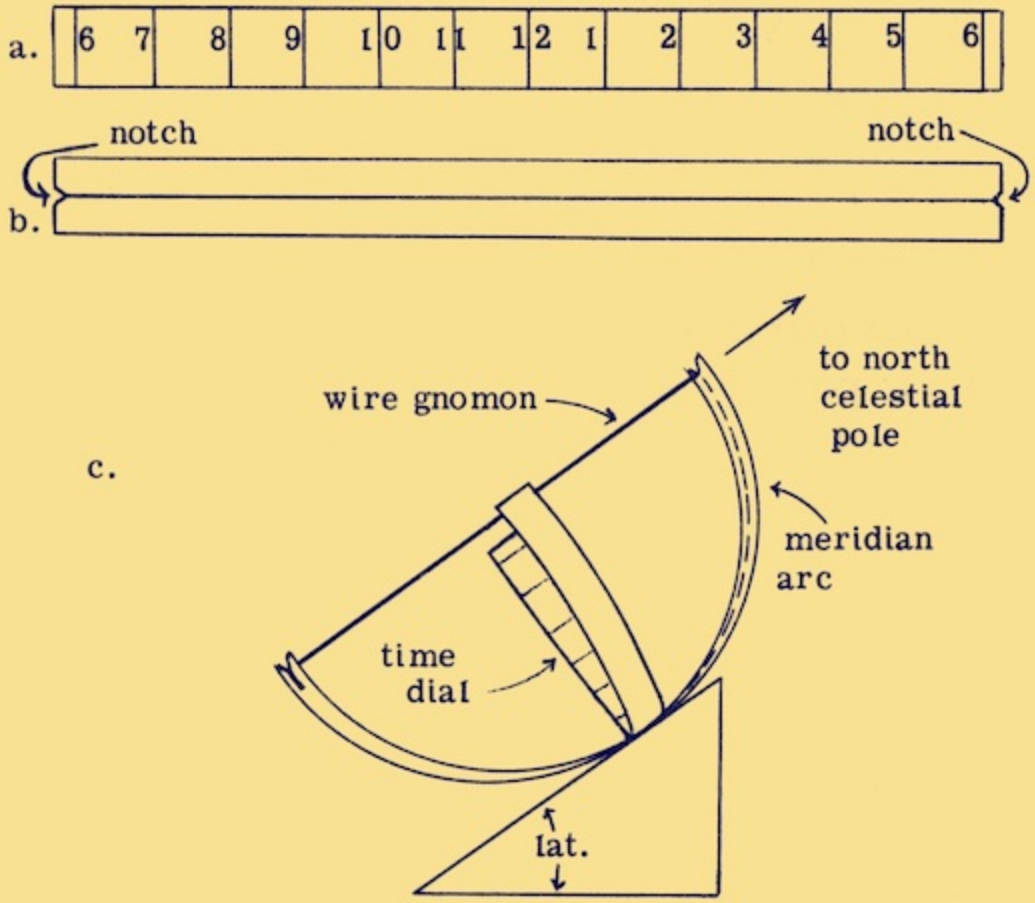

Fig. 9

just beneath the 12 o'clock line, pushing it through until the two centers meet. Match the center line on the meridian arc with the 12 o'clock line. The two half circles will be at right angles to each other.

Bend the fine wire in your unit one-half inch from one end and place it in one of the notches of the meridian arc. Tape the end to the outside of the arc. Measure the wire to the exact length of the diameter of the semicircle and then bend and insert into the other notch.

Secure the wire and cut off any excess (Fig. 9c). Straighten the wire if necessary This serves as the gnomon. Make sure the shadow of the gnomon falls directly on the 12 o'clock line and that the two arcs are at right angles to each other. Then tape the two together just beneath the point where they cross.

Make a right triangular support with the base angle equal to the latitude similar to the one you made for the equatorial dial. However, in this case, make all three triangles the same size. Mount on a square of cardboard. Secure the heliochronometer to the top of this support being sure that the wire gnomon is in line with and parallel to the slant of the latitude. Then orient the heliochronometer so that its gnomon lies along the meridian. The shadow of the gnomon should fall on the 12 o'clock line at solar noon. If you wish to tell standard time shift the time dial so that the shadow will fall on the 12 o'clock line at 12 o'clock standard time.

DAYLIGHT SAVING TIME

In order to tell daylight saving time on a horizontal dial, you cannot twist the sundial around to make the sundial read

an hour later. Why?

The equatorial sundial, however, can be easily made to read daylight time by rotating the dial plate so that the 1 o'clock line is in the 12 o'clock position.

Experiment 14. You can adjust the heliochronometer to read daylight time also. How would you do this?

The models of sundials you have made are just a few typical examples. There are many other interesting dials including reclining dials and portable dials. If you wish to read further on this fascinating subject, here are a number of references:

The Clock We Live On, Isaac Asimov, Abelard-Schuman, New York, 1965.

Sundials, Arthur Robert Green, Macmillan Co., New York, 1926.

Sundials, Roy K. Marshall, Macmillan Co., 1963.

Sundials, R. Newton Mayall and Margaret L. Mayall, Charles T. Branford Co., Boston, 1958.

Appreciation is expressed to Dr. R. Glenn Hall, Assistant Director, Time Service Division, U.S. Naval Observatory, Washington, D. C., for reviewing this booklet.

* * *

Cut out label on other side and paste on box.

Things of science MEMBERSHIP

12 monthly experimental kits — $9.50
(Add $1.50 for outside U.S.A. addresses)